ISSN 2320-5407 International Journal of Advanced Research (2014), Volume 2, Issue 8, 463-470

ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Earthquake Activity in Kishtwar –Dharamshala Region of North-West Himalaya

Sandeep Sharma[1], A. Dasgupta[1], Arjun Kumar[2], Bharanidharan B.[2], Himanshu Mittal[3], Rajiv Sachdeva[3]

1 Chenab Valley Power Projects, J&K, Jammu-180006 INDIA
2 Department of Civil Engineering, Arni University Kathgarh (Indora), Himachal Pradesh, INDIA
3 Indian Institute of Technology, Roorkee-247667 INDIA

Manuscript Info

Manuscript History:

Received: 15 June 2014
Final Accepted: 29 July 2014
Published Online: August 2014

Key words:
Kishtwar, Dharamshala, Main Boundary Thrust, Main Central Thrust, Himalaya, Earthquake.

****Corresponding Author***

Sandeep Sharma
Arjun Kumar
arjundeq@gmail.com

Abstract

In the present study, Kishtwar-Dharamshala region of north-west Himalaya that experienced about 30 earthquakes in last three years having magnitudes between 4.0 to 5.8 has been studied. This region falls in zone IV according to the Seismic Zoning map of India and marked with number of regional and local thrusts faults. This region experienced around 476earthquakes during last 30 years as per records available at Indian Metrological Department. Out of these 476 events around 321 earthquakes have magnitude less than 3.0 and only 7 earthquakes experienced for which the magnitude lies in between 5.0-6.0. The maximum magnitude recorded in this region which was reported by IMD is M5.8 on 1stMay 2013 followed by number of aftershocks. The earthquakes occurred in last 3 years are mainly concentrated in Kishtwar zone and Dharamshala zone about 100 km apart from each other. This activity in Kishtwar spans about 60 km in width and is confined between MBT and MCT. The activity starts at 9 km in depth and extended down 60 km depth in Kishtwar region. While in Dharamshala region this activity is scattered near MBT, spans about 45 km in width and extended below from 10 km to 40 km down in the crust. The stress drops associated with earthquakes in Kishtwar zone varies between 5.8 MPa and 13.0 MPa and for Dharamshala zone between 3.2 MPa and 13.3 MPa.The stress drops observed in these regions are similar to other parts of Himalaya. The average stress drops associated with Himalayan earthquakes are of the order of about 6.0MPa (Kumar et al., 2008; Kumar, 2011). Hence the stress drops associated with these earthquakes doesn't reflect any abnormal behavior. The distribution of this earthquake activity shows the presence of active faults in these regions. As geological processes generally took time of hundred years to occur, so nothing can be inferred about when it will rupture with the available analyzed data. A close monitoring of earthquake activity in these regions is required.

1. Introduction

The Indian plate is moving towards Eurasian plate at a rate of about 3-4 cm per year. As both of these continental plates are composed of with same density materials, so these continental plates get collided. This collision causes the folding and buckling of Eurasian Plate and created the Himalayas and other mountains of Central Asia.

Figure 1 depicts topographic map and the major tectonic fronts of the Indian Plate on north edge along the Himalaya, i.e. Hazara Arc, Himalayan Arc and Burmese Arc (Kumar et al., 2014b). Seismically eastern edge of

Indian plate along Himalaya including Burmese arc is most active as witnessed by various large to great earthquakes. The western edge of Indian plate including Hazara Arc is comparatively less active and generated earthquakes with magnitudes less than 8.0. The central part of Indian plate along the Himalaya is noticed least active and also defined as 'seismic gap' by Khattri (1987) as no large or great earthquakes have been occurred in this region.

Khattri (1987) mapped three seismic gaps in Himalaya– Kashmir gap, Central gap and Assam gap.The Jammu and Kashmir, Himachal Pradesh and Uttarakhand falls under Kashmir gap which is the highest earthquake prone seismic zone.

2. Seismotectonic Setup of the Region:

The Kishtwar and Dharamshala regions are located in north-west part of the Himalaya. The major tectonic features of the regions are Main Central Thrust (MCT) in the north and Main Boundary Thrust (MBT) towards its South. The MCT is considered as one of the most important tectonic features throughout the entire Himalaya almost up to the eastern syntaxis. MCT forms the northern boundary of the lesser Himalayan belt, which is separated from the Frontal Belt by the Main Boundary Thrust (MBT).The MBT is not a single thrust plane and the configuration is produced on the surface by an overlapping of thrust sheets. The Siwalik Belt occupying a sprawling foothill zone consists of outcrops of Tertiary rocks in several folded and faulted strips. The Siwalik present a picture of folded structural belt with broad synclines alternating with steep, often faulted, narrow asymmetric anticlines. The axial planes as well as the strike faults and thrusts on their limbs are steep at the surface and dip more gently northwards at depth (Srikantia and Bhargava, 1998). MCT is terminated against the Kishtwar Fault. The Lesser Himalayan domain is separated from the Great Himalaya by Main Central Thrust (MCT). To the north of Great Himalaya, stretches a vast sedimentary realm of Tethys Himalaya. The Evolutionary model of Himalaya (Le Fort, 1975) reveals that Main boundary Thrust (MBT) represents a younger tectonic activity as compared to Main Central Thrust (MCT), and is more active currently. However, both Main boundary Thrust and Main Central Thrust have been considered as the contemporaneous features in the steady-state model of (Seeber and Armbruster, 1981) and these merge with each other at depth with a common detachment surface. The majority of earthquakes in NW Himalaya are concentrated in the zone between Main Boundary Thrust and Main Central Thrust of shallow focal depth and great Himalayan earthquakes originate at the surface of detachment which represents the upper surface of the under thrusting Indian plate with apparent northward dip of about 15^0 (Ni and Barazangi, 1984).

The seismotectonic investigation carried out by many workers (Seeber and Armbruster 1981; Ni and Barazangi 1984; Thakur 1992; Thakur and Kumar 2002; Kayal 2007; Bollinger et.al, 2007). To understand the ongoing pattern of Himalaya, Seeber and Armbruster, 1981; proposed a steady state tectonic model while Ni and Barazangi (1984), formulated an evolutionary model. These models have highlighted the seismogenic discontinuities as Main Boundary Thrust (MBT), Main Central Thrust (MCT), a plane of detachment (Main Boundary Thrust) and Main Central Thrust (MCT) coincide with this plane at depth and the basement thrust. Most of the seismicity of the region lies between Main Boundary Thrust (MBT) and Main Central Thrust (MCT) as shown in the map.

The most prominent tectonic feature towards the north of the Kishtwar Region is the very extensive Karakoram Fault (KKF), which also had affected the region with a huge dextral offset and is traceable towards northwest through the Shyok suture to the Pamir. This fault extends for almost 1000 Km from Central Pamir to Kumaon Himalaya (GSI, 2000). AltynTagh fault is conjugate of the Karakoram Fault.

In addition to the structural discontinuities sub-parallel to the Himalayan trend, there is a number of faults/lineaments transverse to this fold-thrust belt. The Sundernagar Fault (also known as Manali Fault) is a dextral transverse structure, which extends from Higher Himalaya to the Frontal Belt. This fault is considered to have caused the swing of the Frontal Belt from NW-SE to N-S. The Kaurik fault system of higher Himalaya is characterized by normal faulting exhibiting splays might have ruptured during Kinnaur earthquake of 1975 (GSI, 2000). Of the several transverse faults of limited surface extension, Kishtwar Fault (also known as Suru Fault) is the most prominent one. The left lateral Kishtwar fault has been termed as neotectonic by GSI (2000) and the MCT got terminated against this fault. The entire study area is flanked by a number of faults and thrusts some of them being considered very active (e.g., Main Boundary Thrust (MBT).

The region around Kishtwar and Dharamshala have experienced earthquakes of 30th May, 1885 Sopore, Jammu & Kashmir (Mag. 7.0); 4th April, 1905 Kangra, Himachal Pradesh (Mag. 8.0); 20th Feb 1967 (Mag. 5.5); 19th Jan 1975 Kinnaur, Himachal Pradesh (Mag. 6.2); 26th April 1986 Dharamshala, Himachal Pradesh (Mag. 5.6); 8th Oct. 2005 Muzaffarabad (Mag. 7.6). The Kangra of 1905 cause's death of more than 20,000 people and the Muzaffarabad earthquake of 2005 caused death over 100,000 people in this area [source: IMD and USGS].

3. Results and Discussions

The Kishtwar-Dharamshala region of north-west Himalaya that experienced most destructive/killer earthquakes in India - Kangra earthquake of 1905 (20,000 people) and other nearby Muzaffarabad earthquake of 2005 (1, 00,000 people) has been studied. The seismotectonic map of Kishtwar and Dharamshala regions along with epicenters of earthquakes that occurred in last 30 years with magnitudes 3-4, 4-5, and above 5 on the Richter scale are shown in Figure 3.

Some of the earthquakes occurred in the study region in last three years have been analyzed in detail. The epicenters of these events lie between MBT and MCT. These events are distributed in about 60 km width in Kishtwar and about 45 km near Dharamshala as shown in Figure 4.

Seismicity cross sections are a powerful means for studying the distribution of earthquakes in depth and the relationship between earthquakes and crustal structures (Ni and Barazangi, 1984). The depth-wise distribution of these events have been studied with three cross-section A-A' parallel to MBT & MCT (Fig. 5) and two other cross-sections B-B' (Fig.6) and C-C' (Fig. 7) along the epicenters distribution. The cross-section A-A' shows that the events in Kishtwar region extended down to about 60 Km in crust, while the earthquakes occurred in Dharamshala are confined up to 45 km depth.

The earthquake activity in Kishtwar region as shown in depth section B-B' (Fig. 6) is confined between the MBT and MCT. However, in Dharamshala region the activity is scattered near to MBT as shown in depth-section C-C' (Fig. 7) and one event occurred north side of MCT.

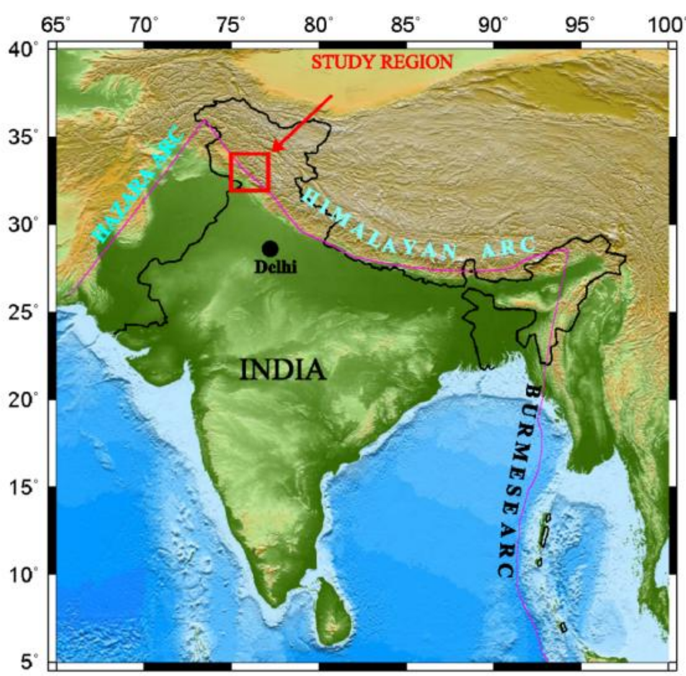
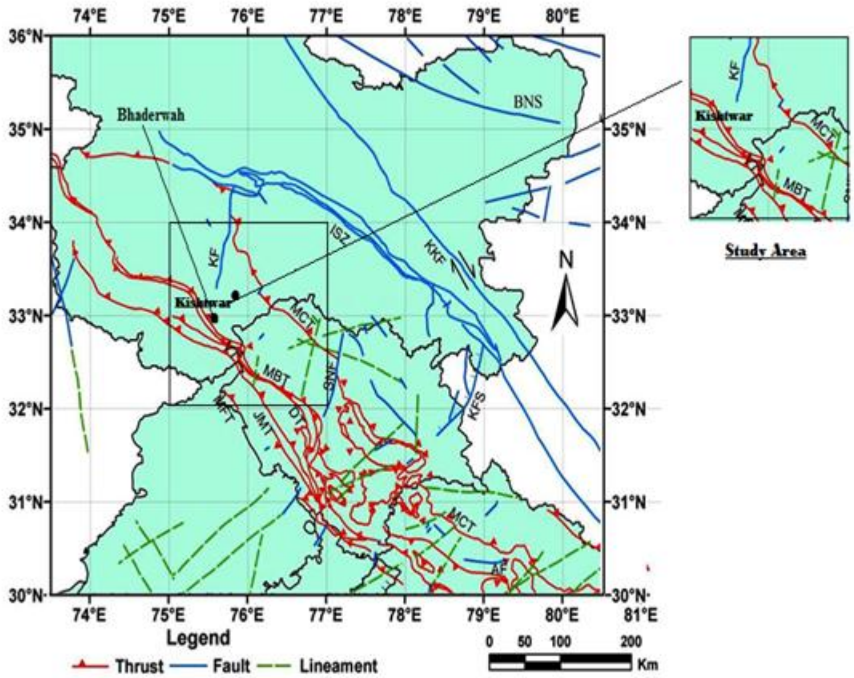


Figure 1.Topographic view of northern edge of Indian plate – Himalayan Arc on upper side, Hazara Arc on left side and Burmese Arc on right side. The study region is shown by red colored rectangle.



MCT	Main Central Thrust	MBT	Main Boundary Thrust
KF	Kishtwar Fault	DT	Darang Thrust
BNS	Bangong-Nujiang Suture	SNF	Sunder Nagar Fault
JMT	JawalaMukhi Thrust	ISZ	Indus Suture Zone

Figure 2. Tectonic Map (GSI, 2000) of North West Himalaya showing various thrusts and faults (Figure after Patil, 2012; Patil et al., 2014).

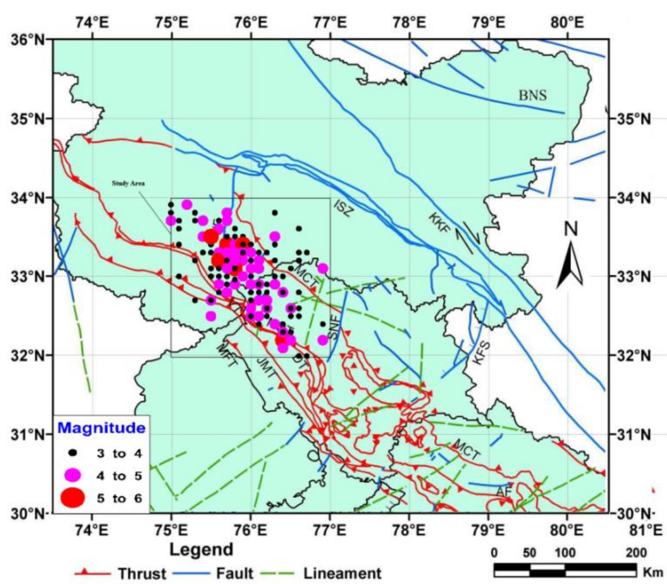


Figure 3: Epicentre map showing earthquakes occurred in Study area around Kishtwar region w.e.f May 1982 to June 2014 (Figure modified after Patil, 2012).

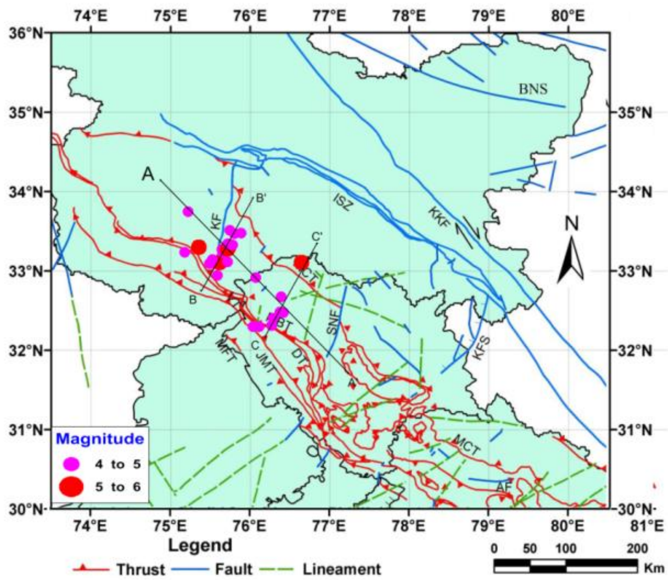


Figure 4.The epicentres of the events occurred in last 3 years.

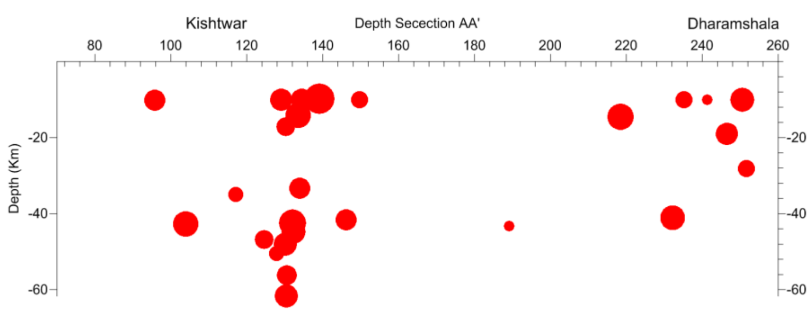


Figure 5. The depth cross section A-A' parallel to MBT.

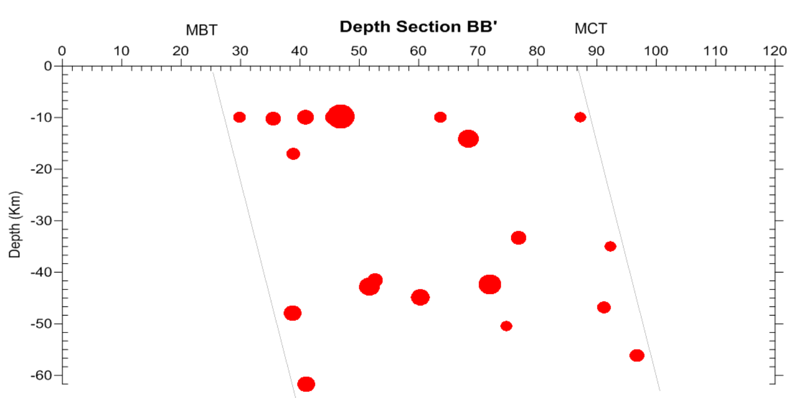


Figure 6.The depth cross section B-B' along the epicenters distribution in Kishtwar region.

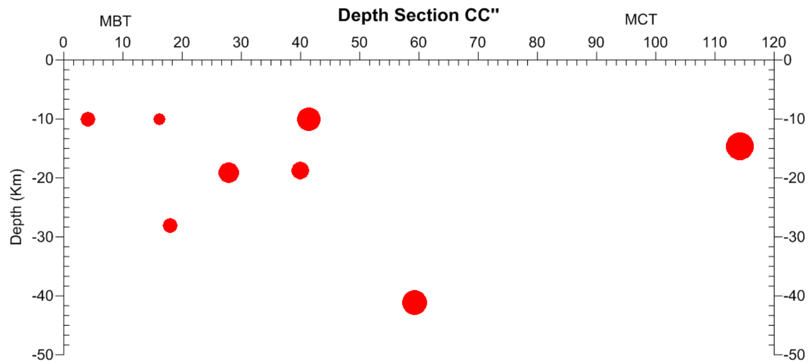


Figure 7.The depth cross section C-C' along the epicenter's distribution in Dharamshala region.

Some of the earthquakes occurred in the study region have been recorded by Indian national strong motion instrumentation network networks (e.g., Mittal et al., 2006; Kumar et al., 2012; Mittal et al., 2012). The recorded acceleration time histories have been analyzed using software EQK_SRC_PARA (Kumar et al., 2012) to infer the values of stress drops during these earthquakes. The estimated values of stress drops have been listed in Table 2. The estimated stress drops for Kishtwar region varies from 5.8 MPa to 13.0 MPa. For Dharamshala region the stress drops are 3.2 MPa to 13.3 MPa. The stress drops observed in these regions are similar to for other parts of Himalaya (e.g., Sharma and Wason, 1994; Wason and Sharma, 2000; Paul et al., 2007; Paul and Kumar, 2010; Kumar et.al., 2006; 2012; 2013a, b, c; 2014; Borkar et al., 2013; Sivaram et al., 2013; Paidi et al., 2013, Parshad et al., 2014; Sen et al., 2014). The average stress drop estimated for Himalayan earthquakes is about 6.0MPa (Kumar et al., 2008; Kumar, 2011). Hence the stress drops associated with these earthquakes doesn't reflect any abnormal behavior.

Table 2:Estimates of stress drops for earthquakes in Kishtwar and Dharamshala regions of NW Himalaya.

Earthquake		**Stress Drop ($\Delta\sigma$)**
Kishtwar Region (Jammu&Kashmir)		
28-07-2011 18:42:34	(Mw 4.4)	11.0MPa
01-05-2013 06:57:12	(Mw 5.7)	5.0 MPa
14-05-2013 20:00:07	(Mw 4.9)	7.2 MPa
09-07-2013 13:49:13	(Mw 5.3)	5.8 MPa
02-08-2013 02:32:05	(Mw 5.4)	13.0 MPa
02-08-2013 21:37:40	(Mw 5.2)	6.0 MPa
Dharamshala Region (Himachal Pradesh)		
2012-10-0203:45:30	(Mw 4.6)	3.2MPa
2012-10-0208:34:54	(Mw 4.9)	13.3MPa
2012-10-0310:49:26	(Mw 4.2)	8.8MPa
2012-11-1120:23:12	(Mw 4.0)	6.9MPa
2013-06-0417:34:50	(Mw 4.8)	10.2MPa
2013-06-0522:04:03	(Mw 4.0)	3.3MPa
2013-07-1317:49:36	(Mw 4.4)	4.4 MPa
2013-07-15 17:49:11	(Mw 4.4)	4.0 MPa

4. Conclusions

This Kishtwar-Dharamshala region falls in zone IV according to the Seismic Zoning map of India and marked with number of regional and local thrusts faults. These regions experienced the Kangra of 1905 cause's death of more than 20,000 people and the Muzaffarabad earthquake of 2005 caused death over 100,000 people in this area. This region experienced around 476 earthquakes during last 30 years as per records available at Indian Metrological Department. Out of these 476 events around 321 earthquakes have magnitude less than 3.0 and only 7 earthquakes experienced for which the magnitude lies in between 5.0-6.0. The maximum magnitude recorded in this region which was reported by IMD is M5.8 on 1stMay 2013 followed by number of aftershocks. The earthquakes occurred in last 3 years are mainly concentrated in Kishtwar zone and Dharamshala zone about 100 km apart from each other. This activity in Kishtwar spans about 60 km in width and is confined between MBT and MCT. The activity starts at 9 km in depth and extended down 60 km depth in Kishtwar region. While in Dharamshala region this activity is scattered near MBT, spans about 45 km in width and extended below from 10 km to 40 km down in the crust. The stress drop associated with earthquakes in Kishtwar zone varies between 5.8 MPa and 13.0 MPa and for Dharamshala zone between 3.2 MPa and 13.3 MPa. The stress drops observed in these regions are similar to other parts of Himalaya. The average stress drops associated with Himalayan earthquakes are of the order of about 6.0 MPa (Kumar et al., 2008; Kumar, 2011). Hence the stress drops associated with these earthquakes doesn't reflect any abnormal behavior. The distribution of this earthquake activity shows the presence of active faults in these regions. As geological processes generally took time of hundred years to occur, so nothing can be inferred about when it will rupture with the available data. A close monitoring of earthquake activity in these regions is required.

5. Acknowledgements

The authors are thankful to Prof. Ashwani Kumar and Prof. Ashok Kumar for their valuable guidance and support to carry out this research work. The authors are profusely thankful to Ministry of Earth Sciences (MoES) for funding the project under which data was collected. Authors also express their gratitude to the management of Chenab Valley Power Projects for their constant support and encouragement.

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